Physical Environment and Sciences

Glacier Monitoring in Denali National Park and Preserve

by Guy Adema

Abstract

Glaciers are a major feature in Denali National Park and Preserve (Denali), covering about one million acres—17% of the park. Glacier behavior in Denali varies from steady flow glaciers controlled primarily by topography and climate, to erratic surge-type glaciers. This variety offers opportunities to monitor glacier dynamics dominated by climate as well as those that are influenced by other factors. A formal glacier monitoring program began in Denali in 1991 as part of the National Park Service's Long-term Ecological Monitoring Program, in cooperation with the U.S. Geological Survey and the Geophysical Institute at the University of Alaska Fairbanks.

National Park Service photo with inset photo by Bradford Washburn, UAF Rasmuson Library

Top: Figure 1. Over 1 million acres of Denali National Park are covered by ice.

Left: Re-occupation of historic photo sites provides insight to the magnitude and distribution of glacier change since the early 1900s.

The fundamental aspect of the program is an "index" method, or single point mass balance monitoring. Two index monitoring sites are maintained in Denali, on the Kahiltna and Muldrow glaciers. Both monitoring sites are at or near the equilibrium line altitude (ELA) and attempt to measure conditions on the south and north sides of the Alaska Range, respectively. Since monitoring began in 1991, the Kahiltna glacier index site has had a slightly positive mass balance and a variable velocity that ranges from 590 to 820 feet per year (180-250 m/yr). Seasonal balances are on the order of +/- one meter of water equivalency per year. During the same time period, the Traleika glacier has shown a consistently negative mass balance within a slightly narrower range of seasonal balances, with flow rates between 66 and 230 feet per year (20-70 m/yr). These data, combined with glacial extent measurements and reconstruction of historical photos, have documented significant change in Denali's glacial system.

Introduction

The objective of the glacier-monitoring program in Denali is to establish baseline conditions of selected glaciers and to detect and understand glacial processes. Pursuing this objective will allow detection of the effects of climate fluctuations as they happen and to better understand the natural evolution of the Denali landscape, much of which has been shaped by glacial processes. The data obtained can be used to test dynamic models of climate and glacier flow and emerging hypotheses regarding the effects of climate change. The data also may help identify the effects of these changes on other related systems, such as the discharge of glacier-fed rivers.

In May 1990, the National Park Service (NPS) proposed

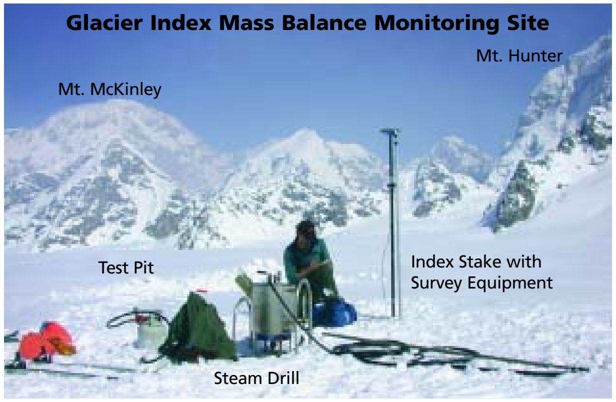

Figure 2. Glacier index measurement sites include fixed stakes which are surveyed twice per year to calculate mass balance, movement rates, and changes in surface elevation.

global climate change research on Alaska-region glaciers in park units. An informal workgroup of specialists from Denali, the U.S. Geological Survey (USGS), and the University of Alaska Fairbanks (UAF) began scoping what a sustainable monitoring program might look like, applying experience from existing glacier monitoring and research programs. In early 1991, the NPS held a glacier research workshop in Alaska to develop recommendations about glacier monitoring *(Sturm 1991)*. Seventy people—representing universities, federal and state agencies, and interested individuals—attended a three-day workshop on glacier research and monitoring. The goal of the workshop was to promote cooperation and coordination between groups. Those in the workshop recommended a glacier monitoring system, examined the nature of this system, and how it would fit in with ongoing or planned research programs at Denali. A steering committee was formed to develop an interdisciplinary group of interested parties to pursue the objectives for the newly conceived permanent coordinating group for North American Glacier Observations. The glacier monitoring ideas identified at the conference and refined by the steering committee, evolved into the glacier monitoring program at Denali.

By March 1991, specialists from USGS, UAF and Denali targeted two glaciers to monitor, representing two distinct climatic zones in the park, the Traleika and the Kahiltna glaciers. In order to keep the measurements relatively simple and sustainable for long-term monitoring, the designed program uses single point measurement method, referred to as the *index method*. This method adopts established USGS glacier monitoring standards and involves visiting an *index site* twice per year to measure mass balance, volume change, and rate of ice flow. Index site data can then be compared to trends measured on other glaciers.

An index site is a fixed site on a glacier where a single pole, 1 inch (2.5 cm) in diameter and 20 to 40 feet (6-12 m) long, is melted into the ice near the equilibrium line (ELA) of the proposed glaciers. The proposed glaciers all met the required criteria of having a simple geometry, spanning a large elevation range, being in a distinct climatic region, and being representative of other glaciers in the area.

Site selection, installation, and monitoring of survey monuments on the Kahiltna and Traleika glaciers were completed in the spring of 1991. It continued as a cooperative program with the USGS—specifically, Larry Mayo—from 1991 to 1997. Keith Echelmeyer (UAF) has also been an instrumental cooperator with the program since its inception, helping with program development, technical assistance, field advisement, and informal review.

The index site measurements are just one element of the glacier monitoring program at Denali. Contemporaneous to the initiation of index monitoring, a comprehensive program was envisioned that also included:

- (1) establishing photo points for monitoring glacial surface and termini changes,
- (2) terminus surveys,
- (3) investigating sites for automated weather stations near each index site, and
- (4) performing longitudinal surveys to monitor ice volume changes and surge-type glaciers.

This glacier monitoring vision was included in a larger NPS effort to institutionalize monitoring of ecosystem change—the Long-term Ecological Monitoring Program. Denali would become a prototype park for the NPS Long-term Ecological Monitoring Program in 1992. A glacier monitoring element was incorporated into the conceptual watershed model because of glacial presence in many headwaters in Alaska's ecosystems, their role in shaping the physical environment, and their importance as early indicators of global climate change. Glacier monitoring became a part of the Denali's prototype monitoring effort, and glaciers have been identified as a vital sign in the subsequent NPS Central Alaska Network Inventory and Monitoring Program.

The glacier monitoring program has expanded to include many of the elements originally envisioned in a comprehensive program. In addition to index site measurements, glacial extent measurements (field and remotely-sensed), surge activity monitoring, change detection observed through comparative photography, and discharge monitoring activities have been implemented.

Methods

Index Site Measurements

A formal field manual for conducting index site measurements was completed in 2001 that describes the necessary elements for data collection and processing. Two times per year, at the end of the accumulation season and at the end of the ablation season, the index stakes on the Kahiltna and Traleika glaciers are surveyed and test pits are dug near the sites. The data are interpreted for single-point mass balance, surface velocity, and surface elevation change. Data collection has evolved from traditional surveying to survey-grade GPS measurements *(Figure 2)*.

Glacial Extent Measurements

Changes in glacial extent are documented in two ways. Field-based termini measurements are performed on a number of glaciers on a rotating basis, with each being visited about every 10 years. In order to gain a better idea of change across the entire park, remotely-sensed images are interpreted for glacial extent and provide an overall, long-term quantification of change. The park-wide data series currently consists of 1950s USGS black and white aerial photography, 1980s aerial high altitude photography, cloudless, full-coverage, 2001 LandSat Thematic Mapper Scene, and most recently, one meter resolution IKONOS imagery that is currently being acquired. The imagery is manually analyzed and glacier extents are digitized.

Comparative Photography

Through a cooperative effort with USGS, historic photos are been acquired from the early 1900s through the 1970s, taken by early explorers, NPS personnel, scientists, and visitors. We select high quality images for reproduction based on content and identifiable landforms. The sites are revisited and the photos are reproduced as accurately as possible. Accurate reproductions allow for estimates of volume and extent change, as well as providing powerful interpretive images.

Glacier Surge Event Monitoring

About half of Denali's glaciers are surge-type glaciers, which alternate between normal and surging flow regimes. The processes that control surge activity are not well understood, but the most commonly accepted theories relate surging to sub-glacial hydrologic processes. When glacial surges occur, the NPS monitors the activity and collects basic data to help understand the processes involved, including movement rates, surge-front measurements, and photographic documentation. One of the most highly visible surge-type glaciers is the Muldrow Glacier, viewed by most park visitors from the Eielson Visitor Center. Its surge cycle suggests that it could surge in the relatively near future. In preparation, we have taken actions to collect data to better understand and interpret the potentially dramatic change to the landscape. Movement targets have been installed on the glacier, photopoints have been created, a discharge gauge was installed, and LIDAR data has been collected to provide a digital elevation model (DEM) of the glacier's surface. LIDAR is an optical range finding technology operated from an airplane which produces high resolution terrain information with vetical accuracies less than 1 foot (0.3 m), allowing for accurate surface change calculations and change detection.

Results

Index Site Data Highlights

Preliminary mass balance data from the Kahiltna and Traleika glacier index sites appear in Figures 3 and 4, respectively. Casual observation of these data suggests some interesting findings. With regard to mass balance, there does not appear to be a strong trend for the Kahiltna Glacier *(Figure 3),* though Traleika Glacier *(Figure 4)* has been consistently negative throughout the study. Flow rates for Kahiltna Glacier have been steady at approximately 656 feet (200 m) per year and the glacier has thinned by about 10 feet (3 m) since 1991. The Traleika Glacier, however, has exhibited much more interesting behavior. The surface height of Traleika Glacier has increased some 82 feet (25 m) since 1991 despite the negative annual mass balances and the rate of flow has nearly doubled. Because flow rate is partly a function of the ice thickness (under normal flow conditions), the increase in speed is consistent with the thickening of the ice. The cause of the glacier's thickening, however, is less clear. A strong possibility is that Traleika Glacier is storing ice in advance of the next major surge of the Muldrow Glacier, of which the Traleika is a tributary ice stream. Surging glaciers may thicken and increase in speed near their equilibrium line prior to a surge. The Muldrow Glacier has surged approximately every 50 years. The last surge of the Muldrow occurred in 1956.

Another interesting finding appears in the anti-correlation between the annual mass balances of Kahiltna and Traleika Glaciers. Comparison of the equilibrium line altitudes (ELA) shows that in years in which the balance of Kahiltna Glacier is positive, that of Traleika Glacier is negative, and vice versa (with the exception 1992). The

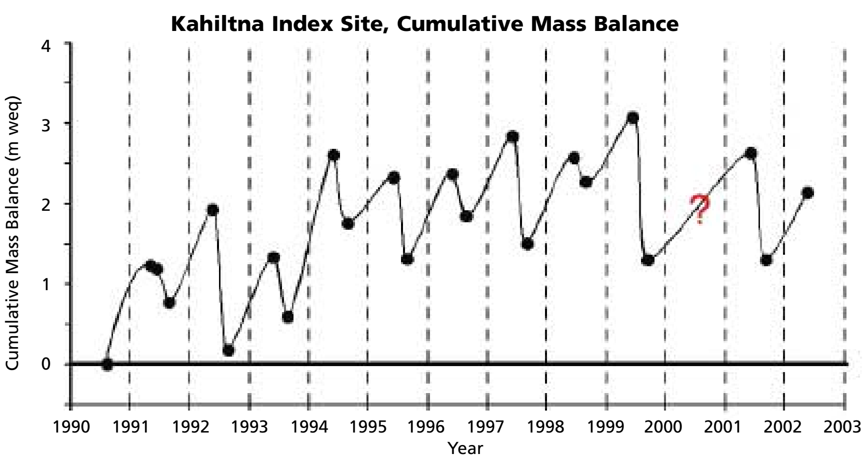

Figure 3. The Kahiltna Glacier index site has shown a slightly positive mass balance since 1990, expected as the site is slightly above the equilibrium line.

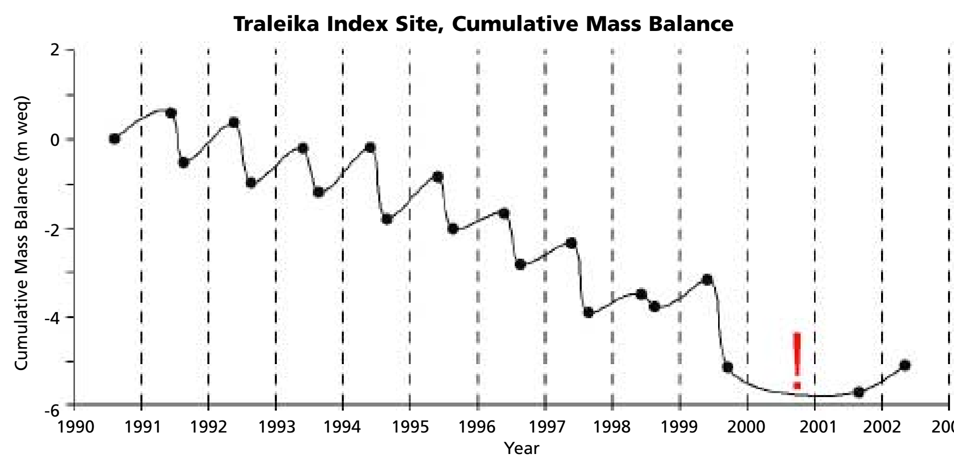

Figure 4. The Traleika Glacier shows a steady negative mass balance since 1990.

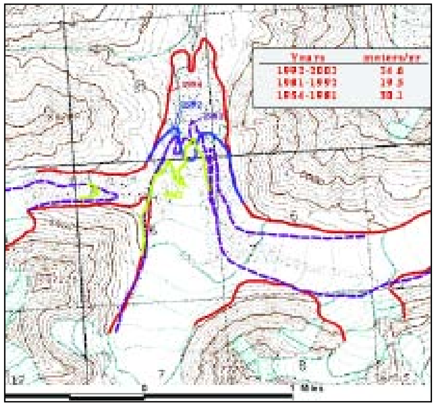

Figure 5. The terminus of the Middle Fork Toklat Glacier has retreated at an average rate of 82.3 feet (24.7 m) meters per year since 1954.

high ELA on Kahiltna Glacier in 1992 was the result of a coating of volcanic ash from the eruption of Mt. Spurr (south of the park on the Alaska Peninsula), which increased melting by heat absorption. This condition was observed in the field. In all other years, the anti-correlation is obvious. Further analysis would determine the cause of the anti-correlation. Possible explanations are that the orographic effect of Mt. McKinley causes snow fall and cloud cover to concentrate on only one side of the mountain in a given year, or that an annual variation in climate exists between the two sides of the Alaska Range.

Glacial Extent

No named Denali glaciers are in an advancing state. Most are actively downwasting and retreating. The rates of retreat are slower than in coastal areas due to a thin veneer of moraine material that insulates the ice and slows retreat. A comprehensive inventory comparing park-wide imagery from 1954, the 1980s, 2001, and 2005-2007 is in process that will help quantify the change. Figure 5 shows the Middle Fork Toklat Glacier, it has an average retreat rate of 79 feet (24 m) per year, for the years 1992 to 2002.

Cursory volume loss estimates of the Middle Fork Toklat glacier were calculated by comparing centerline elevation data surveyed in August 2002, compared with USGS elevation data taken from 1954 aerial photography. The area of the glacier surface was taken from the terminus study measured in the field August 2002 and aerial photos. The total volume change from 1954-2002 is -1.17×10^{10} ft^3 (-3.30×10^8 m^3). The rate of volume change is -2.43×10^8 ft/yr (-6.88×10^6 m^3/yr). Longitudinal surveys on the East Fork Toklat glacier also indicate a loss of over 10 feet (3 m) per year of water equivalency. Further analysis is expected to reveal similar results on other lower elevation glaciers. The data from our coarse measurements are consistent with that of Arendt et al. *(2002),* which calculated volume loss of glaciers around Alaska.

Detailed elevation data (LIDAR) was collected in 2006 on the Muldrow and Traleika glaciers for comparison with 1976 topographic maps made by Bradford Washburn. The data will provide a comprehensive view of volume change for a complete glacier system.

Comparative Photography

Re-creating historic photos has proved a powerful tool for understanding glacial change. Figure 6 shows the Teklenika Glacier has lost almost 900 feet (274 m) vertically and has retreated significantly between 1919 and 2004. We are continually collecting additional historic photos and find similar change across the lower elevations of the park, dramatically highlighting the rate of glacial change in Denali and the resulting landscape effects.

Surge Monitoring

During the surge of the Tokositna Glacier in 2001, maximum ice velocities of over 6.5 feet (2 m) per day were measured, the surge front was surveyed, and the outflow was sampled. The data gathered will yield valuable insight to the mechanisms of surging glaciers. The events were discussed in Echelmeyer et al. *(2002)* and were also published in multiple newspaper articles and television broadcasts in 2001. The park surveys surge-type glaciers in late winter each year to detect surge activity. Glacier movement and discharge measurements on the Muldrow Glacier will provide detailed data in the event of a surge.

Conclusions

A glacier monitoring program is in place at Denali National Park and Preserve that is designed to observe and quantify the primary trends affecting the park's glaciers. Through analysis of the mass balance, photographs, and glacial extent records, trends of Denali's glaciers will be recorded and available for broad-scale relations to climatic and ecological changes. The glaciers of Denali will prove a valuable measure of the rate and impact of climate change.

Acknowledgements

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